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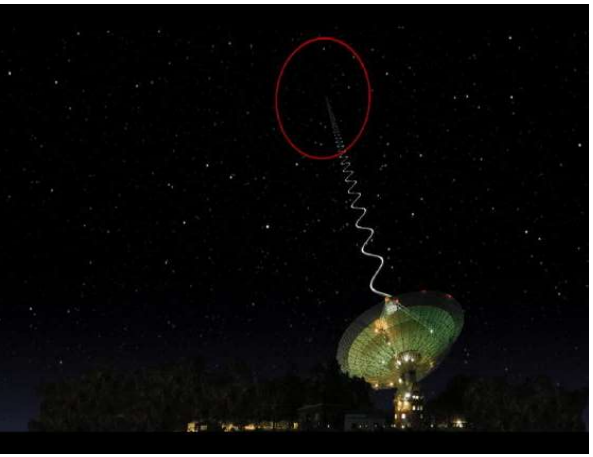

Optimization of MS-GEC Method To Study Complex Microwave Structures

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Abstract

This work presents the interest of using the MS-GEC as multi scale method, in its new formulation, to model complex structures. This formulation gives a new criterion to select active modes based on coupling between structure sub-domains contrarily to classic criterion based on classifying active modes through their cut off frequencies. A preliminary study is demonstrated to classify active modes. Then, this can avoid problem of badly scaled matrices and guarantees the MS-GEC stability against active modes and frequency.

Keywords

MS-GEC, complex structures, active modes.

Biography

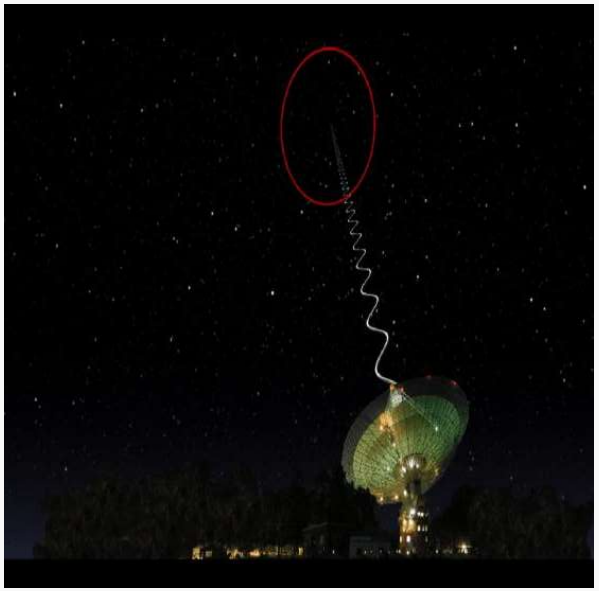
Mohamed HAJJI was born in Tunisia, in 1985.
He received Bachelor's degree in Applied Physics from Superior School of Science and Technic of Tunis (ESSTT), and the Ph.D. degree in Telecommunications from National School of Engineering of Tunis (ENIT).
He is currently a researcher with the Sys'Com Laboratory, National Engineering School of Tunis (ENIT). His current research interests simulation and modeling of antenna and microwave components designed for communication systems.

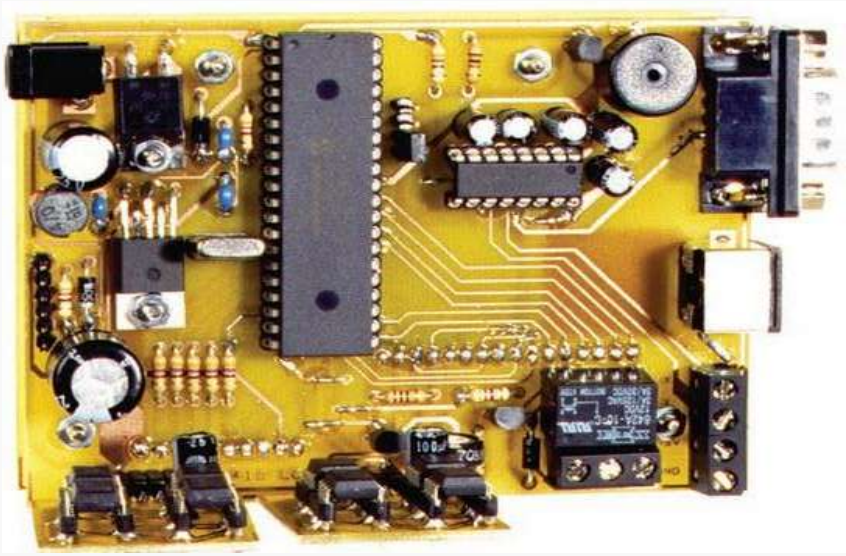
Context

- The integration of new Services in Telecommunications.

- Improvement of performances of Antennas and HF circuits.

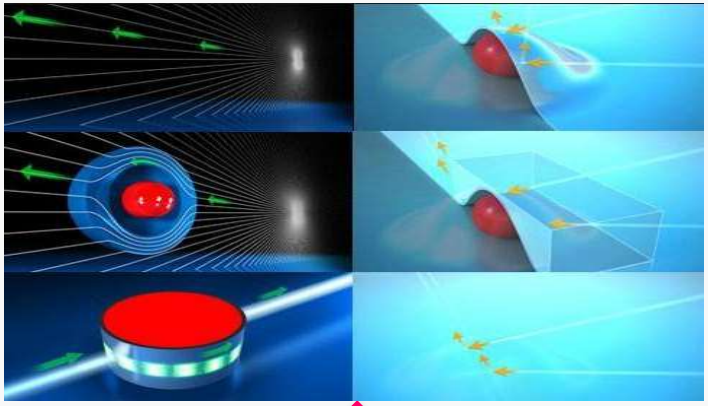
➡ Design and Realization of new circuits.



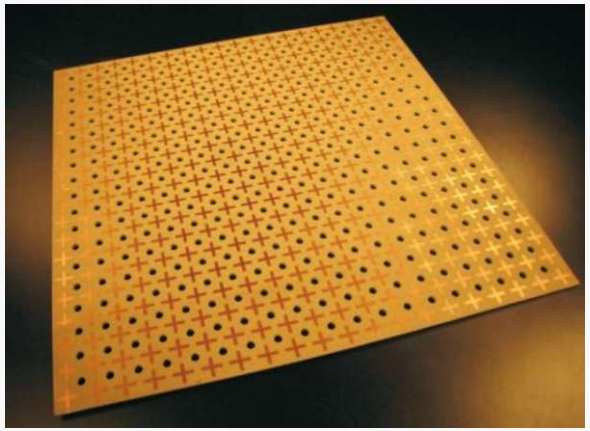


Context

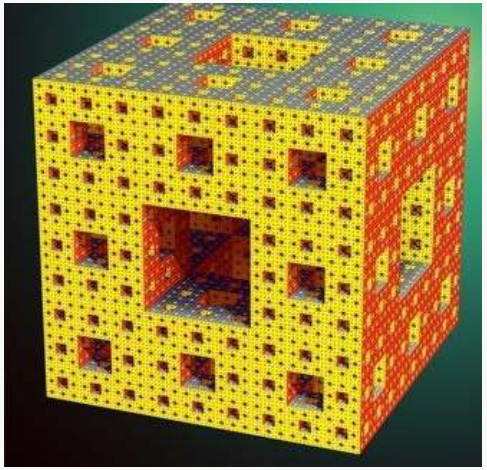
Metamaterials



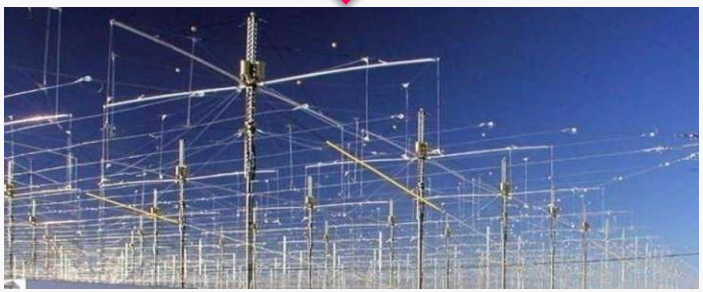
FSS



Fractals



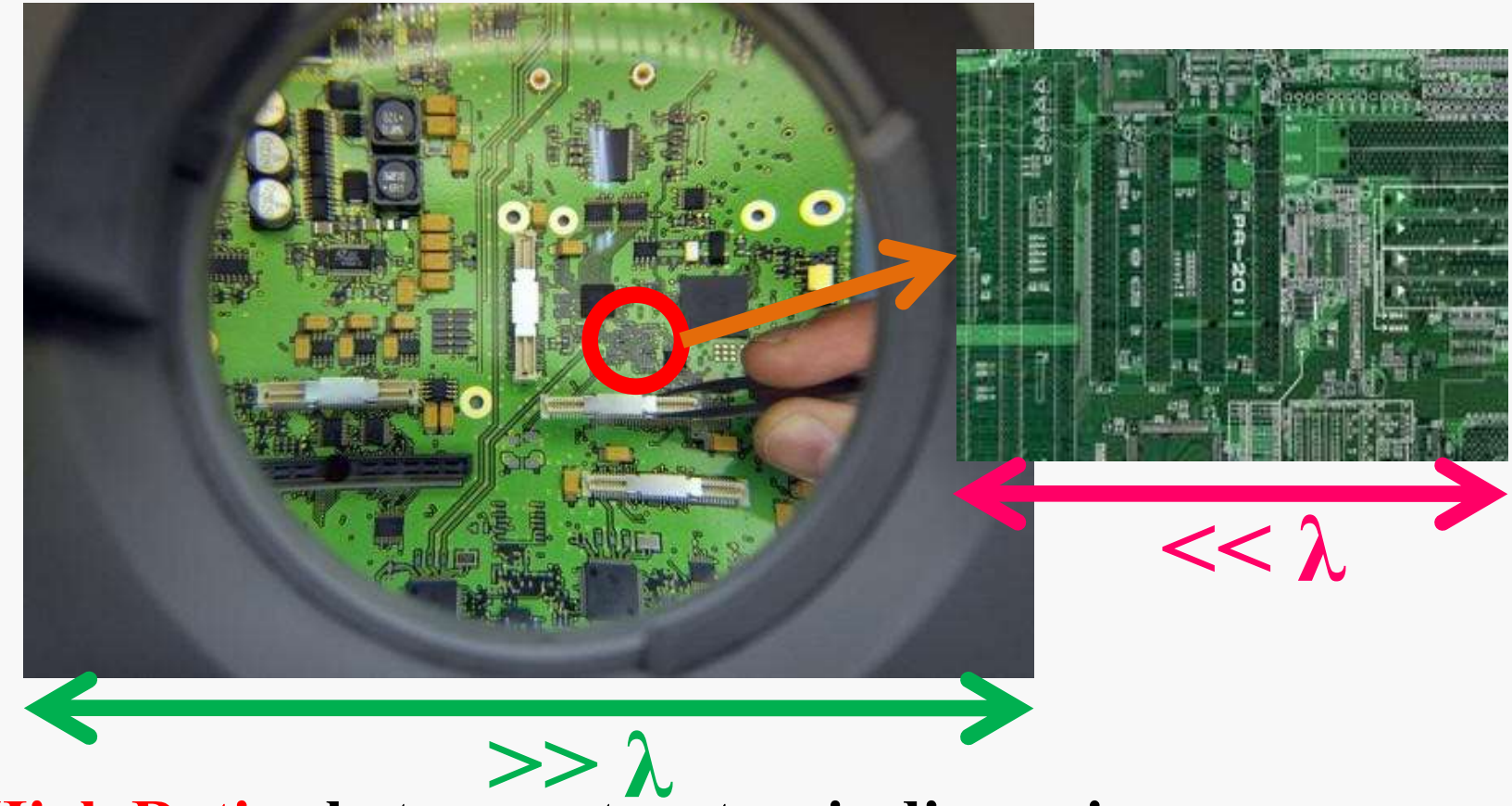
Novel Technologies



Antenna arrays

Context

Multi-scale aspect



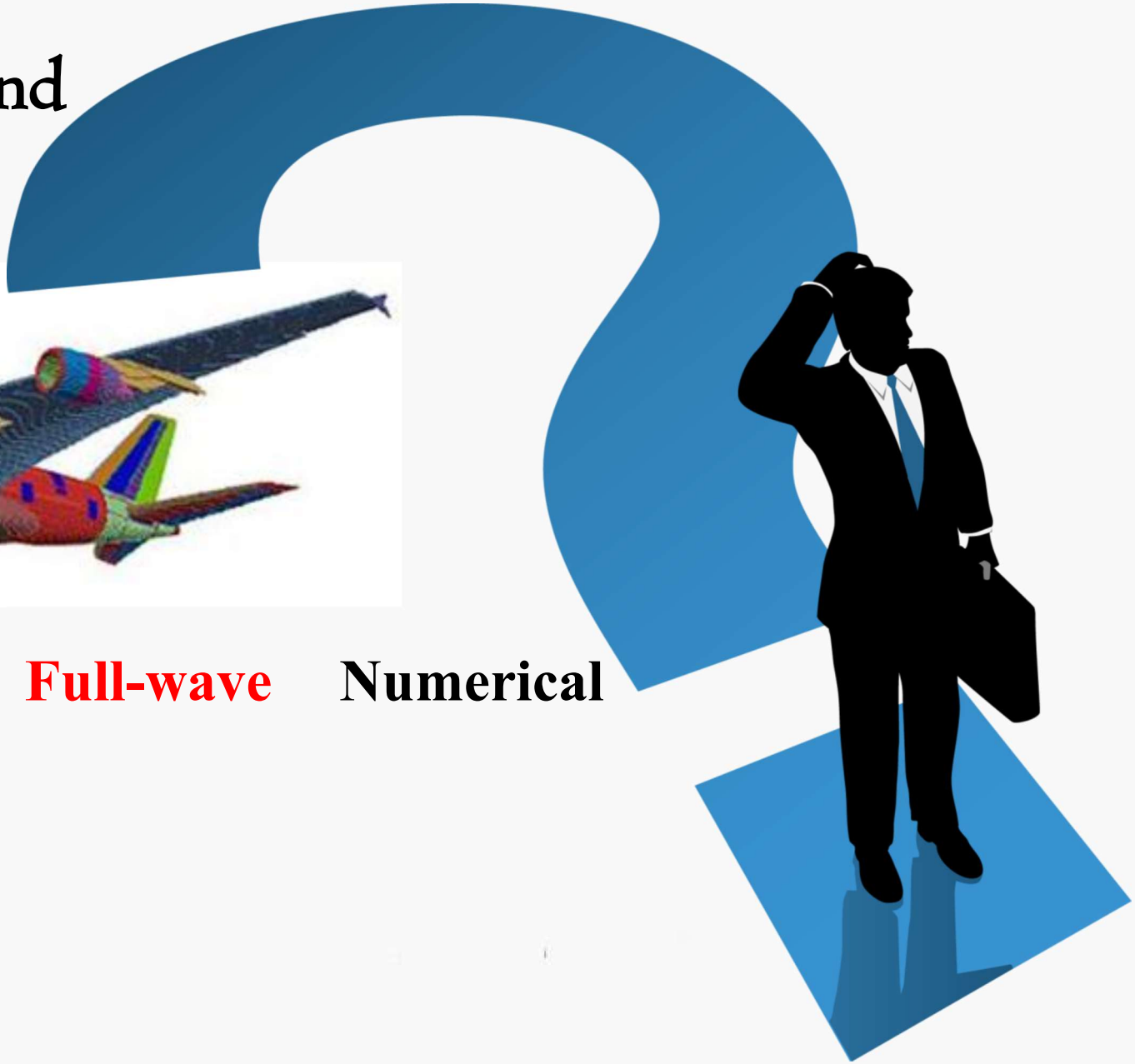
- **Very High Ratios between structure's dimensions.**

➡ Complexe Structures

EM phenomena ➡ Need to have EM models

Modeling?

- Diffraction and Radiation circuits



- **Limitation of Full-wave Numerical methods.**
  - **FDTD:**
  - **TLM:**
  - **MoM:**
  - **FEM:**

Modeling?

➔Multi-scale Methods principle

- **1. Partitioning the structure in sub-domains.**
- **2. EM computation of each sub-domains separately.**
- **3. Integration of sub-domains and total computation.**

Alternative of GEC method → **MS-GEC**

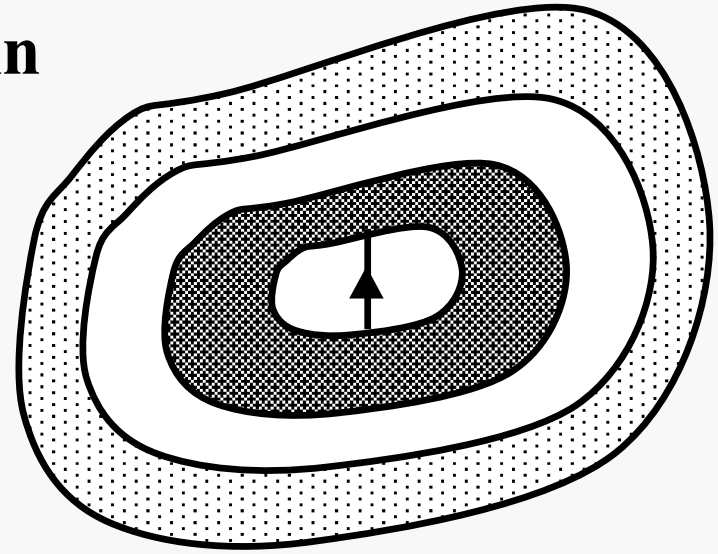
Outline

1. Description of MS-GEC method
2. New Approach MS-GEC: preliminary study
3. Validation of the New Approach MS-GEC
4. Conclusion

1 Description of MS-GEC method

Description of MS-GEC method

- Principle: **Decompose the whole problem in several sub-problems simpler to resolve.**

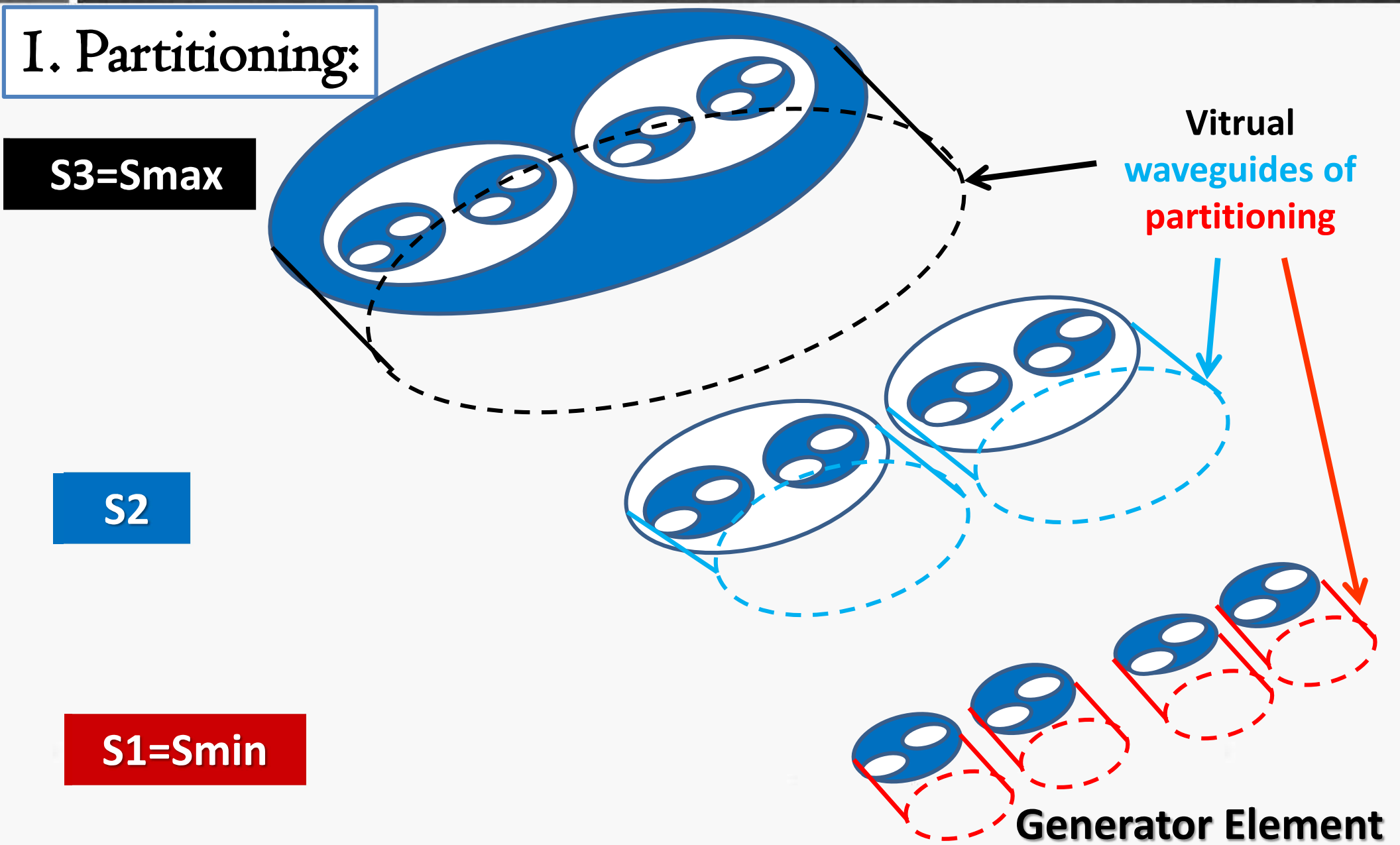


- Different Steps

1. **Partitioning the structure in sub-domains.**
2. **Multimodal Excitation of sub-domains by active modes .**
3. **Determination of surface impedance operators.**
4. **Compute the input impedance and current and field's densities.**

Description of MS-GEC Method

I. Partitioning:



Description of MS-GEC method

2. Multi-modal Excitation (Active modes):

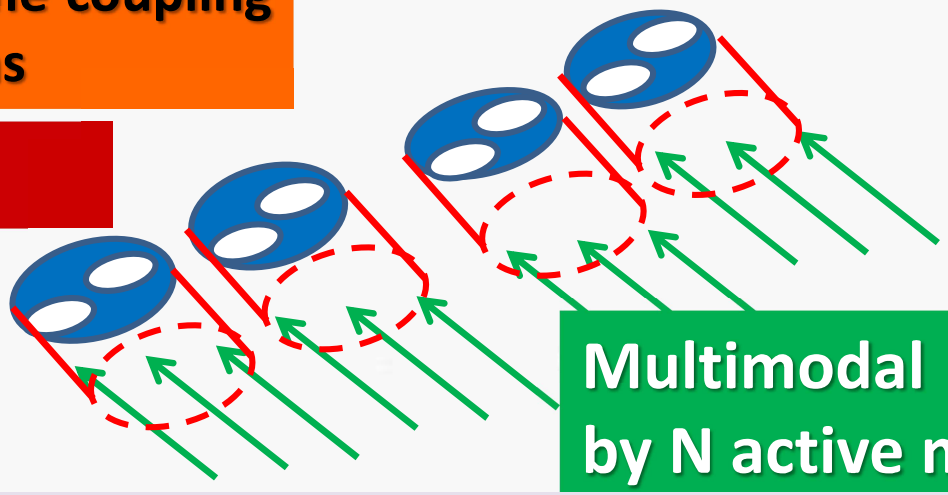
Active modes: Propagatifs or evanescents which permit the coupling of different discontinuities.

➡ Contribute in the coupling between sub-domains

Passive modes: Modes Localized in the vicinity of discontinuity.

➡ Don't contribute in the coupling between sub-domains

- Starting by S1=Smin

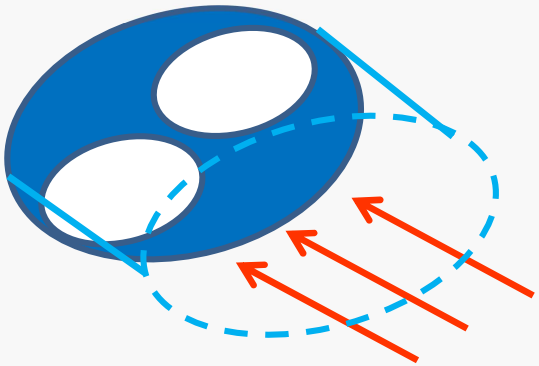


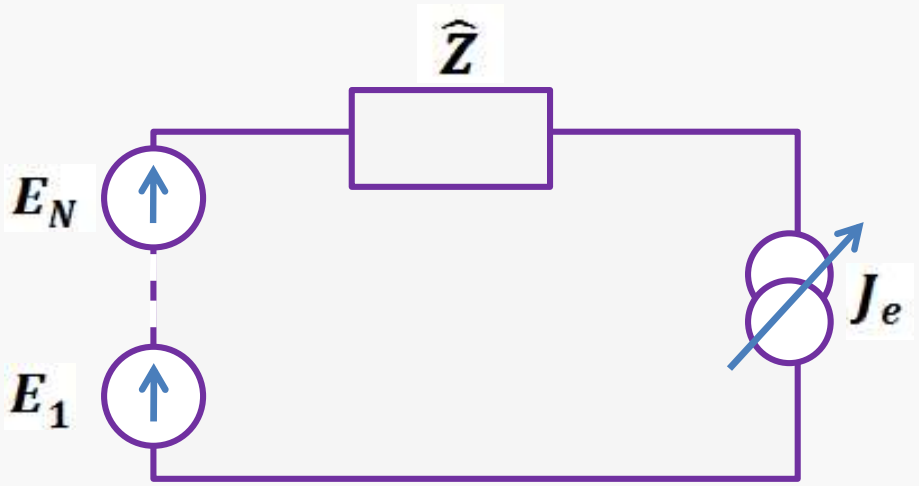
Multimodal excitation by N active modes

Description of MS-GEC method

3. Determination of surface impedance operators:

S1=Smin **N active modes**



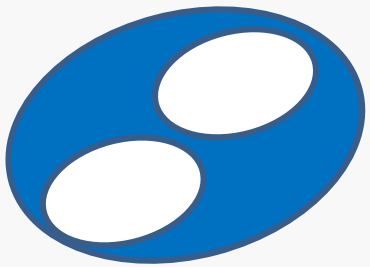


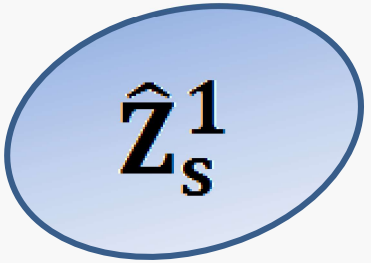
Surface Impedance matrix

$$\begin{array}{c} \\ E_1 \\ E_2 \\ \vdots \\ E_N \end{array} \begin{array}{c} \begin{array}{cccccc} E_1 & E_2 & \cdots & \cdots & \cdots & E_N \end{array} \\ \begin{pmatrix} \langle E_1 \mid E_1 \rangle & \cdots & \cdots & \cdots & \langle E_1 \mid E_N \rangle \\ \cdot & & & & \cdot \\ \cdot & & \cdots\ \cdots\ \cdots & & \cdot \\ \cdot & & & & \cdot \\ \langle E_N \mid E_1 \rangle & \cdots & \cdots & \cdots & \langle E_N \mid E_N \rangle \end{pmatrix} \end{array}$$

Surface Impedance operator

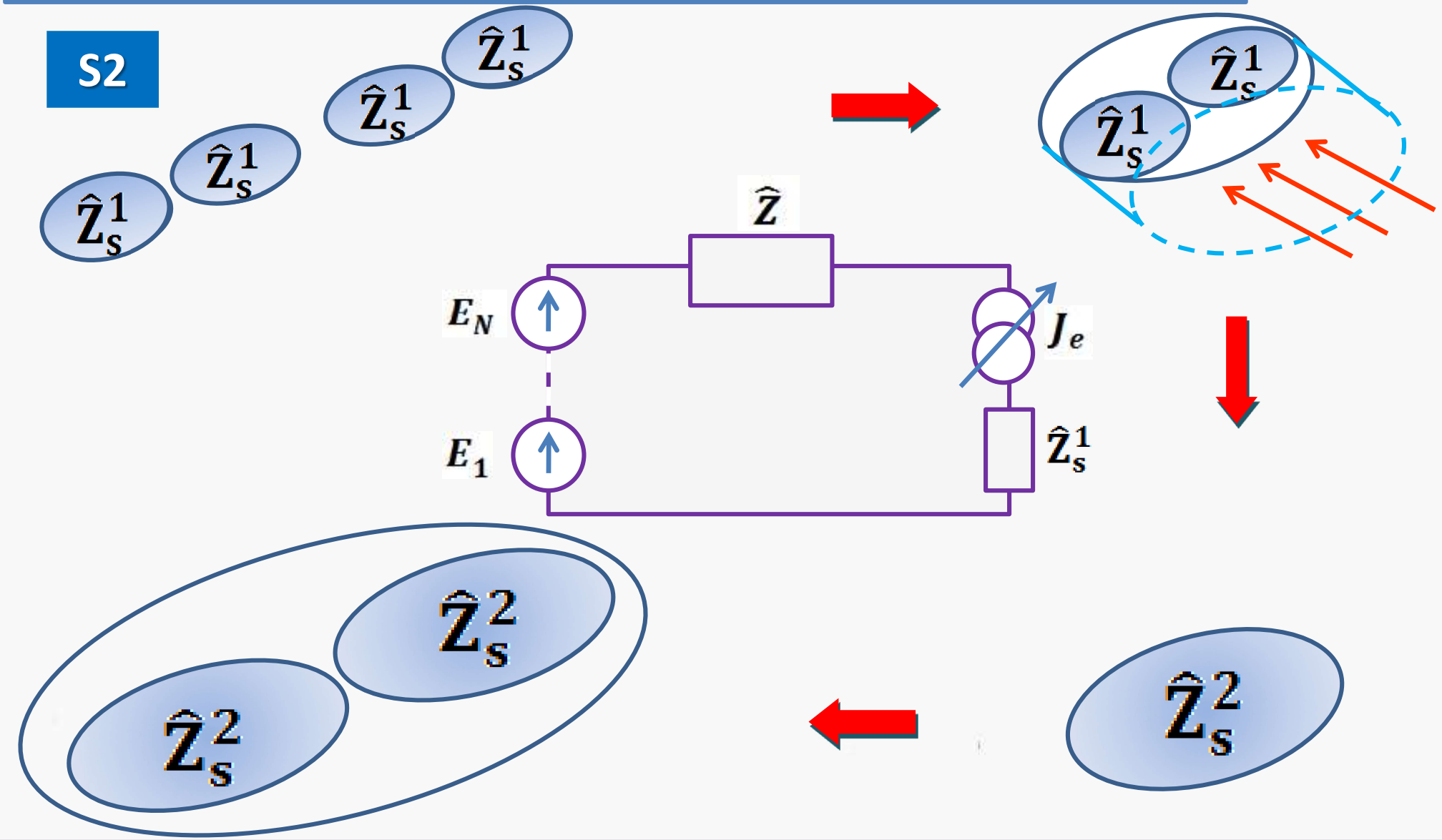
$$\hat{Z}_s = \sum_{i=1}^{N} \sum_{j=1}^{N} |f^i\rangle Z_s(i,j) \langle f^j|$$





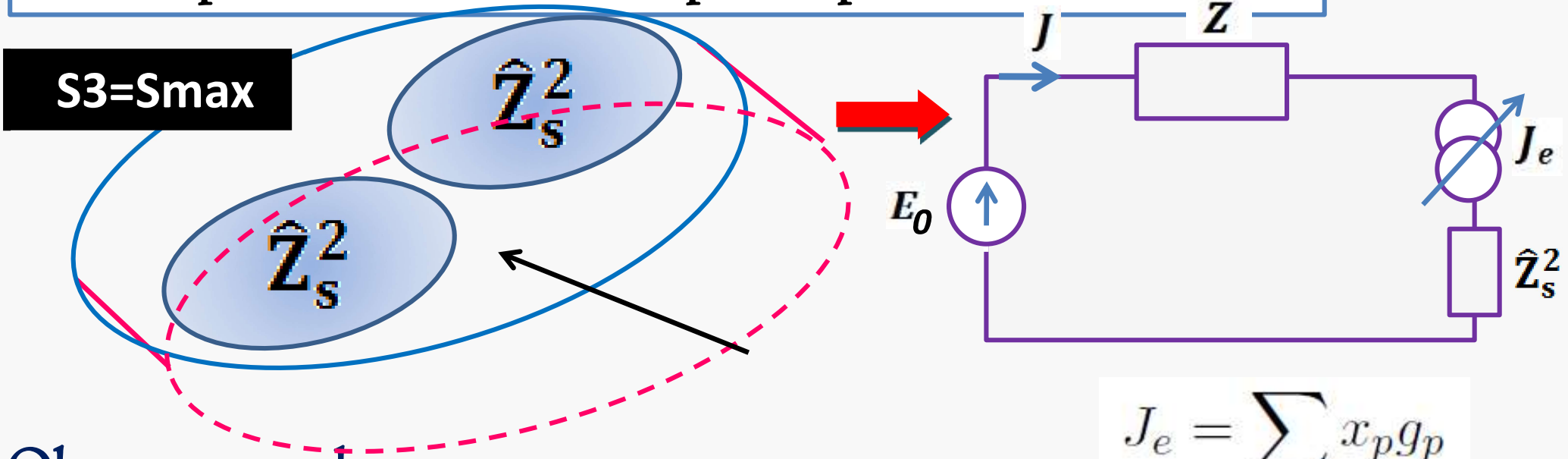
Description of MS-GEC method

3. Determination of surface impedance operators:



Description of MS-GEC method

4. Compute the structure's input impedance:



$$J_e = \sum x_p g_p$$

$$J = \sum I_m f_m$$

Ohm and Kirchhoff laws

$$\begin{cases} J = -J_e \\ E_e = E_0 + (\hat{Z} + \hat{Z}_s^2) J_e \end{cases}$$

Galerkin

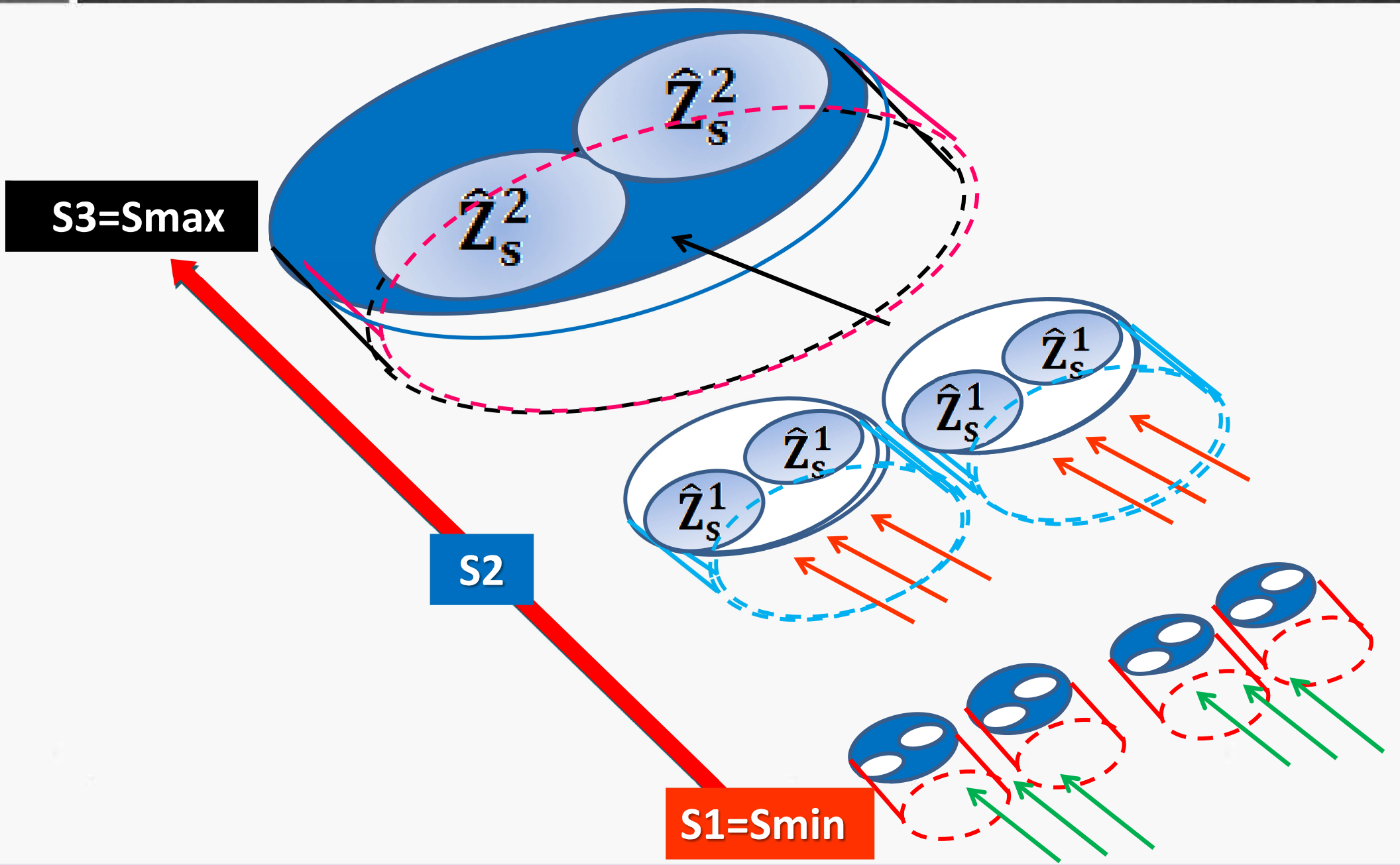
$$\begin{pmatrix} I \\ 0 \end{pmatrix} = \begin{pmatrix} 0 & -A^T \\ A & B \end{pmatrix} \begin{pmatrix} V_0 \\ X \end{pmatrix}$$

$$A_i = < f_0, g_i >$$

$$Z_{in} = \frac{1}{A^T B^{-1} A}$$

$$B(i,j) = < g_i, (\hat{Z} + \hat{Z}_s^2), g_j >$$

Description of MS-GEC Method



Optimization of MS-GEC

Surface impedance operator → $\hat{Z}_s = \sum_{i=1}^{N}\sum_{j=1}^{N} |f^i\rangle Z_s(i,j) \langle f^j|$ ← **Active mode**

Aim? **Optimisation of the number of active modes constituting the surface impedance operators.**

➡ **Reducing the CPU time.**

How? New Criterion of active modes selection.

~~Cut-off frequency~~

New definition of active modes.

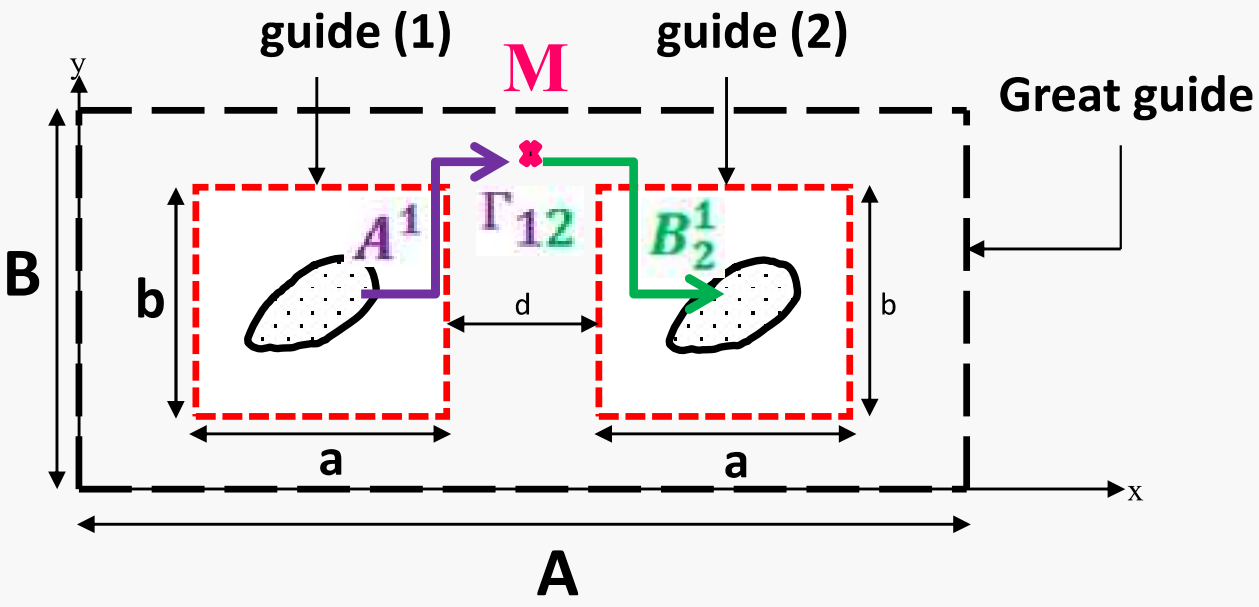
This is based on Intensity of Coupling

Preliminary Study

2

New Approach MS-GEC: preliminary study

Studying the EM coupling between partitioning waveguides



$$A^1 = \sum_{st} a_{st}^1 f_{st}^1$$

$$B^1 = \hat{\Gamma} A^1$$

$$\hat{\Gamma} = \sum_{mn} |f_{mn}\rangle \Gamma_{mn} \langle f_{mn}$$

$$B_{2,pq}^1 = \langle f_{pq}^2, B^1 \rangle = \langle f_{pq}^2, \hat{\Gamma} A^1 \rangle$$

$$B_{2,pq}^1 = \sum_{st} \langle f_{pq}^2, \hat{\Gamma} a_{st}^1 | f_{st}^1 \rangle$$

$$B_{2,pq}^1 = \sum_{st} a_{st}^1 \langle f_{pq}^2, \hat{\Gamma} | f_{st}^1 \rangle$$

$$\mathbf{B}^{1}_{2,pq} = \sum_{st}\sum_{mn} a^{1}_{st}\langle f^{2}_{pq}, \mathbf{F}_{mn}\rangle \Gamma_{mn}\langle \mathbf{F}_{mn}, f^{1}_{st}\rangle$$

$$\mathbf{B}^{1}_{2,pq} = \sum_{st} \mathbf{a}^{1}_{st}\, \Gamma(pq, st)$$

$$\begin{pmatrix} B^1_{2,11} \\ B^1_{2,12} \\ B^1_{2,13} \\ \cdot \\ \cdot \\ B^1_{2,pq} \\ \cdot \\ \cdot \\ B^1_{2,PQ} \end{pmatrix} = \begin{pmatrix} \Gamma(11,11) & \Gamma(11,12) & \dots & \dots & \Gamma(11,ST) \\ \Gamma(21,11) & \dots & \dots & \dots & \Gamma(21,ST) \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \Gamma(PQ,11) & \dots & \dots & \dots & \Gamma(PQ,ST) \end{pmatrix} \begin{pmatrix} a^1_{11} \\ a^1_{12} \\ a^1_{13} \\ \cdot \\ \cdot \\ a^1_{st} \\ \cdot \\ \cdot \\ a^1_{ST} \end{pmatrix}$$

Coupling matrix

$$[\mathbf{B}^{1}_{2}] = [\Gamma][\mathbf{a}^{1}]$$

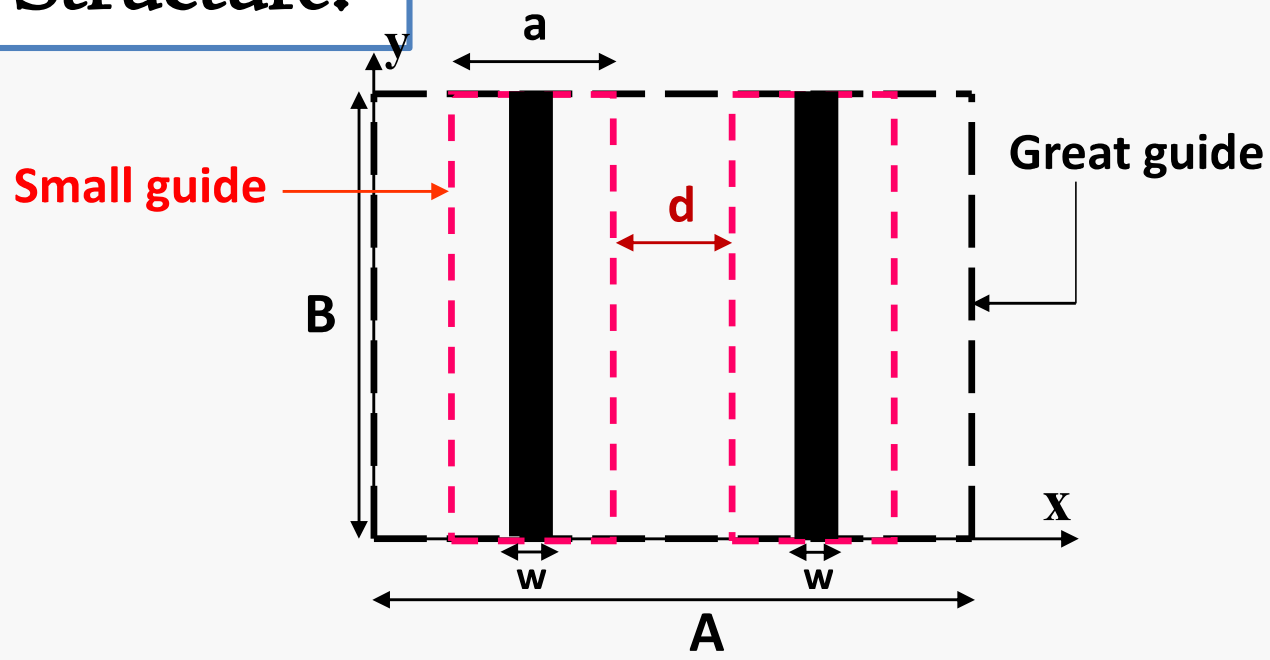
$$\Gamma(pq, st) = \sum_{mn} \langle f^{2}_{pq}, \mathbf{F}_{mn}\rangle \Gamma_{mn}\langle \mathbf{F}_{mn}, f^{1}_{st}\rangle$$

3

Validation of the New Approach MS-GEC

Validation of the New MS-GEC

Studied Structure?



A=60mm
B=20mm
W=4mm
F=1GHz

- Studying the intermodal coupling (coupling matrix)
  - Selection of active modes
  - Optimization of partitioning parameters

Validation of the New MS-GEC

Selection and classification of active modes

The Most coupled modes between the two waveguides

Guide (1)	Guide (2)	|Γ|
TEM	TEM	0.1614
TEM	TE1,0	0.0261
TE1,0	TEM	0.0261
TEM	TE3,0	0.0032
TE3,0	TEM	0.0032
TEM	TE2,0	0.0030
TE2,0	TEM	0.0030

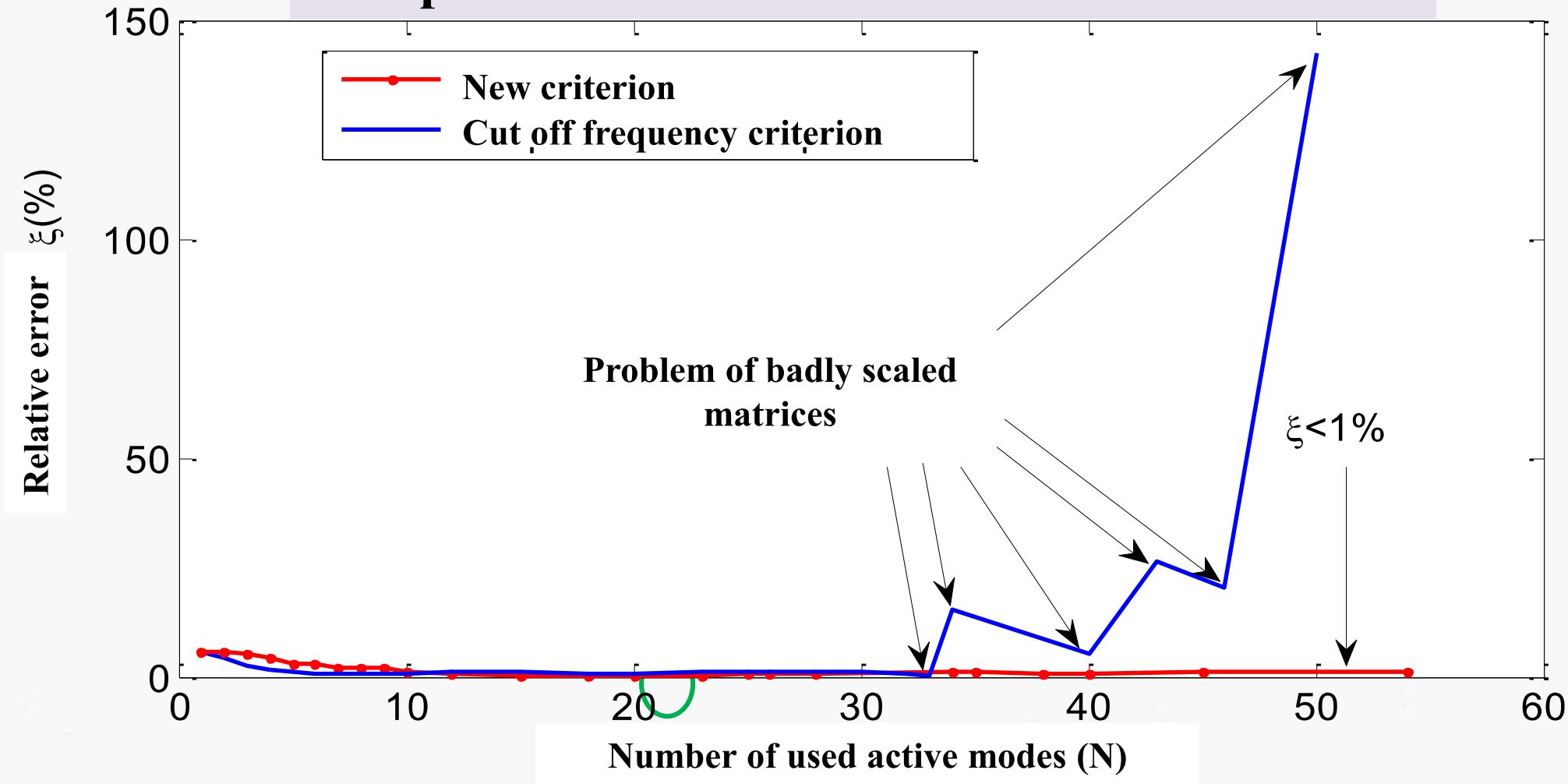
→ Active modes

→ **TEM , TE1,0 , TE3,0 , TE2,0, TE5,0 , TE4,0 , TE7,0, TE9,0 , TE6,0, TE11,0, TE8,0, TE13,0, TE15,0, TE10,0, TE17,0, TE12,0, TE19,0, TE21,0.....**

Validation of the New MS-GEC

Optimisation of active modes selection criterion:

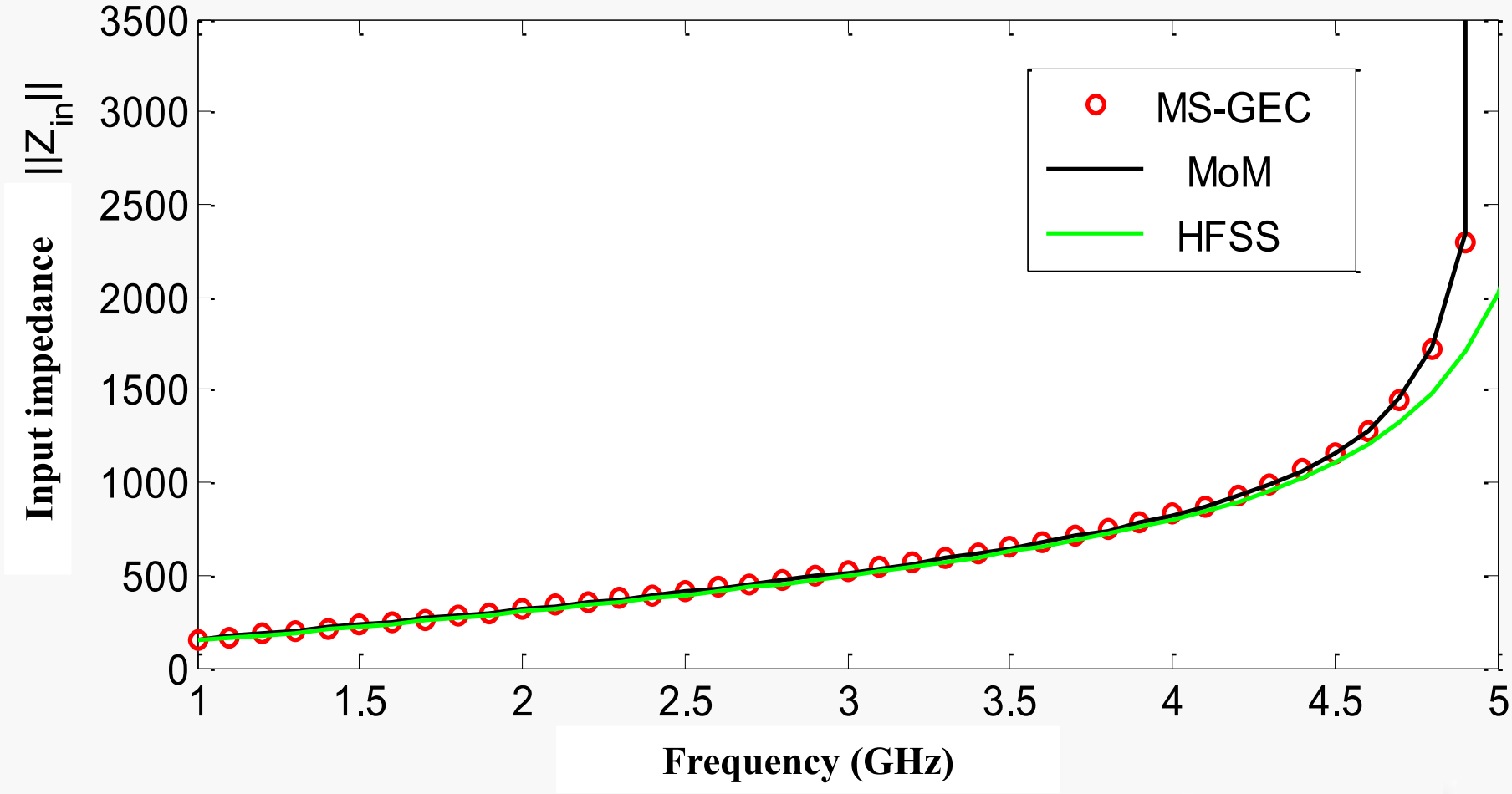
Comparison: MS-GEC to MoM-GEC



New criterion ➡ **Stability of MS-GEC.**

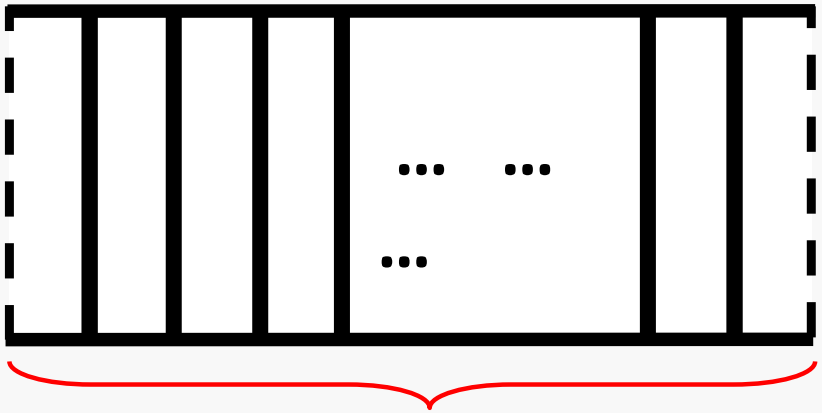
Validation of the New MS-GEC

Behavior over a frequency range

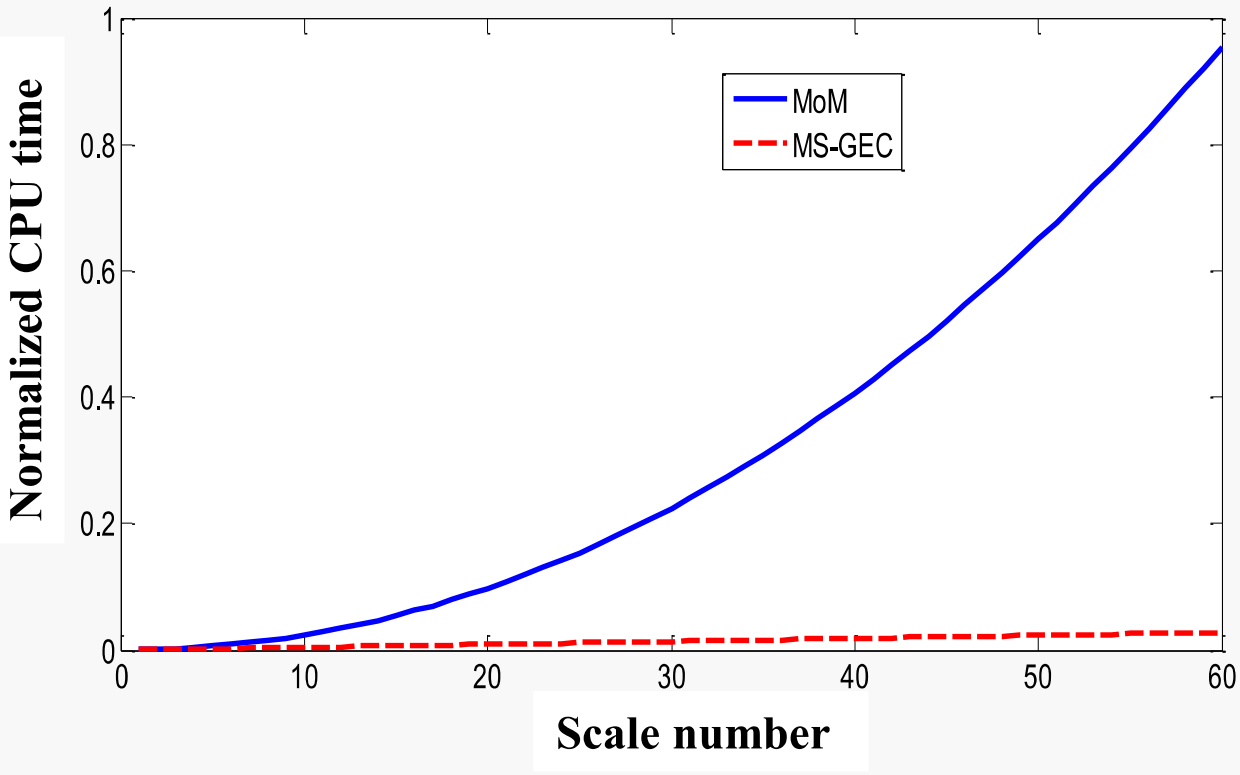


➡ **Stability of the MS-GEC over a frequency range.**

Interest of the New MS-GEC



Multi-scale Structure - k scales



Scale number (k) increases

More important Gain in CPU time is achieved

Conclusion

Conclusion

- **New approach MS-GEC.**

- **Coupling study**
  - **New criterion of active modes classification.**

➡ **Optimization of surface impedance operators.**

- **Considerable Reduction of CPU time.**

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